Acoustic Tomography With Navy Sonars

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LONG-TERM GOALS

The long-term goal is to understand and predict the coherence of sound in the ocean.

OBJECTIVES

We will compare the coherence of broadband acoustic signals at basin-scales with predictions. Degradation of coherence will be modeled using spectra of internal waves.

APPROACH

Data will be collected from a variety of Navy sonars. Traditional means to process the signals will be done including beamforming, coherent averaging (when dealing with periodic signals), correcting for Doppler shifts (when dealing with mobile sonars), and matched filtering (when a replica with the emitted waveform is available). The data will be interpreted using rays and the sound speed insensitive parabolic approximation (Tappert *et al.* 1995) . The acoustic models will be used in conjunction with oceanographic models that contain the best available digital data sets for bathymetry, sound speed fields that vary with range and depth, and internal waves. Spatial coherence will be modeled using the sound speed insensitive parabolic approximation and spectra of internal waves.

WORK COMPLETED

Data have been collected and processed from a wide variety of sonars over basin-scales in the Pacific Ocean. Acoustic models have been developed that incorporate realistic bathymetry, sound speed fields that change with geographic location, and time dependent fluctuations of internal waves obeying a linear dispersion relation. The software for modeling acoustic propagation with the parabolic approximation has been ported to a DOD supercomputer.

A related theoretical investigation has been conducted. At infinite frequency, the only regions of space that influence the time series of a received signal coincide with one or more ray paths joining source to receiver. At finite frequencies, we developed tools to quantify, without approximation, how much any region of space influences a transient signal at a receiver. The regions of space that contribute significantly are referred to as ``regions of influence." At infinite frequency, the region of influence coalesces to one or more ray paths. At finite frequencies, departures from ray paths are wholly due to diffraction. The method has its foundation in the integral theorem of Helmholtz and Kirchhoff.

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14. ABSTRACT
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RESULTS

We simulated the temporally-varying impulse response between a source and receiver at 3250 km in the Pacific (Worcester et al., 1999). The signal was centered at 75 Hz with a bandwidth of 35 Hz. The coherence time was reported to be about 12 min. Our simulation included a climatologically varying sound speed channel with fluctuations of internal waves obeying the Garrett-Munk spectrum. In the simulations, we obtain a coherence time of about 40 min without noise. Most of the gain in simulated signal-to-noise ratio occurs within 12 min. At that point, we find that the signal-to-noise ratio is likely to temporarily decrease. Following this period, we find the signal -to-noise ratio of a coherently integrated simulated signal can increase slightly more until 40 min. It is possible that our simulations are consistent with observations since the observations were apparently not scrutinized for coherence time as a primary goal.

We developed algorithms to process signals on towed arrays. At a distance of 4000 km, we found it possible to coherently process a signal for a duration of at least 10 min. The signal was emitted from ATOC"s 75 Hz, 35 Hz bandwidth source that sits on the bottom near Kauai. There are two causes for coherent degradation of the signal. They are temporal variations of sound speed and receiver motion. It appears that our algorithms are sufficiently adaptive to remove most of the aberrations due to unknown motion of the receiver.

We simulated the horizontal coherence of an acoustic signal at 50 Hz between a source and horizontal array at a distance of 4000 km. The acoustic field is modeled using a 3-D parabolic approximation to the wave equation, where the sound-speed insensitive approximation is used for the vertical slice. The sound speed field is modeled using a spatially varying climatological background. We superimpose a three-dimensional field of sound speed fluctuations due to internal waves obeying the Garrett-Munk spectrum. The time evolution of the field is used to synthesize the temporal variations of the acoustic field at the array. We find that the coherence length is about 10 km.

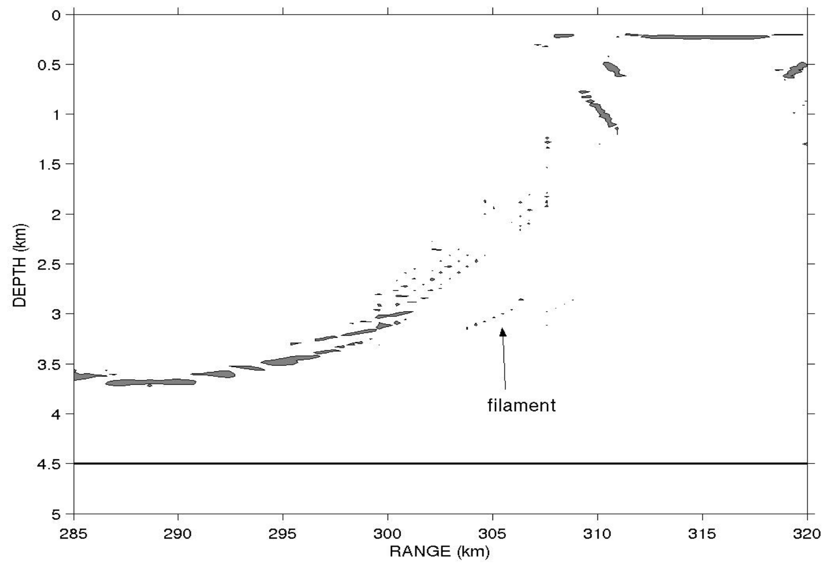

Fig. 1. The top 3 dB of regions in the ocean that influence the received acoustic signal corresponding to a temporally resolved path at the receiver. Only part of the depth-range region is shown to show details near one-half the transmission range.

Our studies of diffraction have led to two conclusions (Spiesberger, 2004,2005). First, signals with 0.05 s resolution near 100 Hz are not primarily influenced along their ray-paths. Instead, the influential regions are broken up and are quite different than the curvy upper turning points of rays in the deep sound channel (Fig. 1). For example, near upper turning points, sounds can be influenced for O(10) km instead of O(1) km as given by the ray limit. Second, at least one theory for acoustic aberrations in the sea assumes that the sounds are influenced within a Fresnel radius of the ray path. We find this assumption to be invalid. Instead, we find that the single length scale concept of influence is too simple (Fig. 1).

IMPACT/APPLICATIONS

Reliable models for coherence of broadband sound are useful for designing and operating sonar systems. They are potentially useful for designing wireless low-frequency communication systems to submarines at long distances.

Accurate estimates for regions that influence sounds between a source and receiver are important in many applications such as surveillance and communications. They are useful for understanding the physics of wave propagation.

RELATED PROJECTS

A Phase I STTR program led by BENTHOS, INC. has started to investigate the feasibility of transmitting low frequency communication signals to submarines over very long distances. That program will use concepts and software originating in this contract.

Drs. Alexander Voronovitch and Vladimir Ostashev (2003) have developed a theory to predict the horizontal coherence scales of sounds in the sea. That theory includes a calculation of the effects of azimuthal coupling of the acoustic field. The numerical results from this contract should be useful for checking the accuracy of their theory at 50 Hz.

Drs. Dzieciuch and Cornuelle (2004) are interested in problems of diffraction.

REFERENCES

Dzieciuch, M., and B. Cornuelle, Raytubes in an ocean acoustic environment, J. Acoust. Soc. Am., 116, 2634 (2004).

Voronovich, A. and Ostashev, V., Studies of horizontal refraction and scattering of low-frequency acoustic signals using a modal approach in signal processing of NPAL data, J. Acoust. Soc. Am., 113 2333 , (2003).

Worcester, P,F., B.D. Cornuelle, M.A. Dzieciuch, W.H. Munk, B.M. Howe, J.A. Mercer, R.C. Spindel, J.A. Colosi, K. Metzger, T.G. Birdsall, A.B. Baggeroer, A test of basin-scale acoustic thermometry using a large-aperture vertical array at 3250-km range in the eastern North Pacific Ocean,' J. Acoust. Soc. Am., 105, 3185-3201 (1999).

Tappert, F. D., Spiesberger, J., and Boden, L., New full-wave approximation for ocean acoustic travel time predictions, J. Acoust. Soc. Am., 97, 2771-2782 (1995).

PUBLICATIONS

Spiesberger, J. Diffraction of nonsinusoidal sound in the sea, J. Acoust. Soc. Am., 115, 2578 (2004).

Spiesberger, J.L., Locating where Transient Signals Travel in Inhomogeneous Media, 31 Jan 2005, http://www.arxiv.org/abs/physics/0501162